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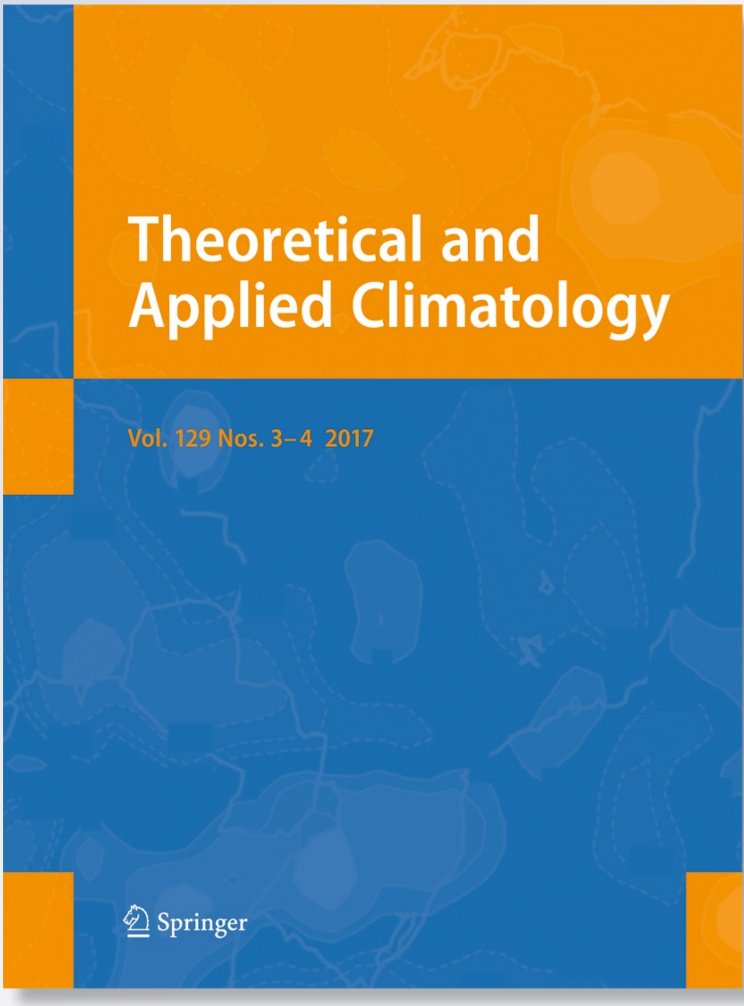

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ORIGINAL PAPER

Rainfall variability and seasonality in northern Bangladesh

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Abstract This paper aimed at the analysis of rainfall seasonality and variability for the northern part of South-Asian country, Bangladesh. The coefficient of variability was used to determine the variability of rainfall. While rainfall seasonality index (SI) and mean individual seasonality index ($\overline{SI_i}$) were used to identify seasonal contrast. We also applied Mann-Kendall trend test and sequential Mann-Kendall test to determine the trend in seasonality. The lowest variability was found for monsoon among the four seasons whereas winter has the highest variability. Observed variability has a decreasing tendency from the northwest region towards the northeast region. The mean individual seasonality index (0.815378 to 0.977228) indicates that rainfall in Bangladesh is "markedly seasonal with a long dry season." It was found that the length of the dry period is lower at the northeastern part of northern Bangladesh. Trend analysis results show no significant change in the seasonality of rainfall in this region. Regression analysis of $\overline{SI_i}$ and SI, and longitude and mean individual seasonality index show a significant linear correlation for this area.

1 Introduction

The analysis of rainfall variability and seasonality is important for Bangladesh due to their tremendous influences towards agricultural water use. Changes in seasonality of rainfall may have substantial impacts on agro-economy of the country. In addition to the agricultural production, changes in rainfall seasonality may damage the dynamic ecosystems, especially in the northeastern Bangladesh because most of the ecosystems of northern Bangladesh are not only depending on total rainfall but also on the seasonal pattern. Besides, due to the increased phenomenon of natural disasters, information about the temporal variability of rainfall is crucial for water resource management and planning.

Variability of rainfall may be defined as the degree to which rainfall amounts vary across an area or through time. It is an important characteristic of the climate of an area. On the other hand, seasonality assesses the seasonal contrasts in rainfall amounts, but not dryness or wetness in an absolute sense (Livada and Asimakopoulos 2005). Barry and Perry (1973) stated that it is possible to define regions with similar precipitation patterns by seasonality indices estimated using harmonic analysis.

Earlier attempts to quantify rainfall seasonality were made in the past during the early 1970s (e.g., Ayoade 1970; Markham 1970; Nieuwolt 1974). Later, Walsh and Lawler (1981) derived an easy to use, rainfall seasonality index based on the methods proposed by Ayoade (1970). A broad application of this modified seasonality index is given by Livada and Asimakopoulos (2005).

Till now, several previous studies reported annual and seasonal rainfall changes (Ahmed and Kim 2003; Shahid and Khairulmaini 2009; Ahasan et al. 2010; Shahid 2010; Hossain et al. 2014; Bari et al. 2016) in Bangladesh. Using Kriging and Mann-Kendall test, Shahid and Khairulmaini (2009) found a moderate variation in inter-annual rainfall and high variation in intra-annual rainfall in Bangladesh during the 1969 to 2003 period. However, no study was carried out on rainfall seasonality and or

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variability for whole Bangladesh or any local scale. Singh and Mal (2014) found that inter-seasonal variability is the highest in plains and lowest in high altitudes at western Himalaya region of India that is neighboring the northern Bangladesh.

This study focused on analyzing the variability and seasonality of rainfall in northern Bangladesh. At first, individual seasonality index was calculated that provides information about the inter-annual variations in seasonality. Later, mean individual seasonality index ($\overline{SI_i}$) was calculated. The Mann-Kendall trend test and the sequential Mann-Kendall test were applied to identify possible trend in rainfall seasonality. We also established correlation between seasonality index and mean individual seasonality index, longitude, and mean individual seasonality index. Variability was measured using the coefficient of variability.

2 Study area

The northern part of Bangladesh was considered in this study. This region covers almost five out of seven climatic zones (Rashid 1991) including the two most distinct climatic regions of Bangladesh namely west (the driest) and northeast (the wettest) region (Fig. 1). Including these two sub-zones will enhance the understanding how rainfall seasonality evolves in extreme environments of Bangladesh. Total south-central zone was not covered due to non-homogeneity of the study area. Figure 1 shows that variations in climatic zones are mainly from west to east. Therefore, studying this part will represent majority of the climatically diverse areas of Bangladesh.

3 Data collection

Monthly rainfall time series data up to the year 2013 were collected from Bangladesh Agricultural Research Council (BARC). BARC collects rainfall data from Bangladesh Meteorological Department (BMD) and process accordingly through its computer and GIS division. There were nine rainfall stations in the selected study area of which one was installed recently. Therefore, we only selected the remaining eight stations (Fig. 1) having at least 50 years of records. Collected rainfall data were then checked for possible inconsistency. To ensure a better output from the study, if monthly rainfall data were unavailable for a whole year, then that year was discarded from the analysis. Stations passing the abovementioned criteria were considered for the next step of analysis. After discarding inconsistent data, we used rainfall time series from 1964 to 2013.

4 Methodology

4.1 Assessing variability of rainfall

We wanted to compare the variation of different sets of observations (annual and seasonal rainfall) about their mean. For this purpose, the coefficient of variability (CV) is a useful parameter. CV is a relative measure of variation that explains the deviation in data series from its central tendencies (Singh and Mal 2014). The coefficient of variability is found by expressing the standard deviation as a percentage of the mean value (Cheung et al. 2008):

$$\mathrm{CV} = \frac{S_x}{\overline{x}} \times 100$$

where CV is the coefficient of variation, s_x is the standard deviation, and $\overline{x}$ is the mean.

4.2 Rainfall seasonality index

Rainfall seasonality index was used to detect the seasonality of rainfall. The seasonality index is given as follows:

$$SI = \frac{1}{\overline{R}} \sum_{n=1}^{12} \left| \overline{X}_n - \frac{\overline{R}}{12} \right|$$

where $\overline{X_n}$ is the mean rainfall of month n, and $\overline{R}$ is the mean annual rainfall.

Though the index only provides a relatively crude arithmetic description of rainfall seasonality, it is an ideal tool for the study of spatial and temporal variation in seasonality (Sumner et al. 2001). Higher index values indicate a greater overall departure from an equal distribution of precipitation through the year (Table 1). However, the resulting index will possess a lower magnitude since the process of averaging smoothes year-to-year "noise" in the monthly rainfall values (Walsh and Lawler 1981; Sumner et al. 2001). This problem can be overcome employing a long-term mean $\overline{SI_i}$ for each site calculated using the individual seasonality index (SI_i). SI_i (Walsh and Lawler 1981) is given as follows:

$$SI_i = \frac{1}{R} \sum_{n=1}^{12} \left| X_n - \frac{R}{12} \right|$$

where R is the annual total rainfall, and X_n is the monthly total rainfall in month n.

Long-term mean $\overline{SI_i}$ for each site using the SI_i over a longer period, j can be found as follows:

$$\overline{SI_i} = \frac{1}{j} * \left(\sum\nolimits_{j=1}^{j=n} SI_{ij}, j = \text{number of year} \right.$$

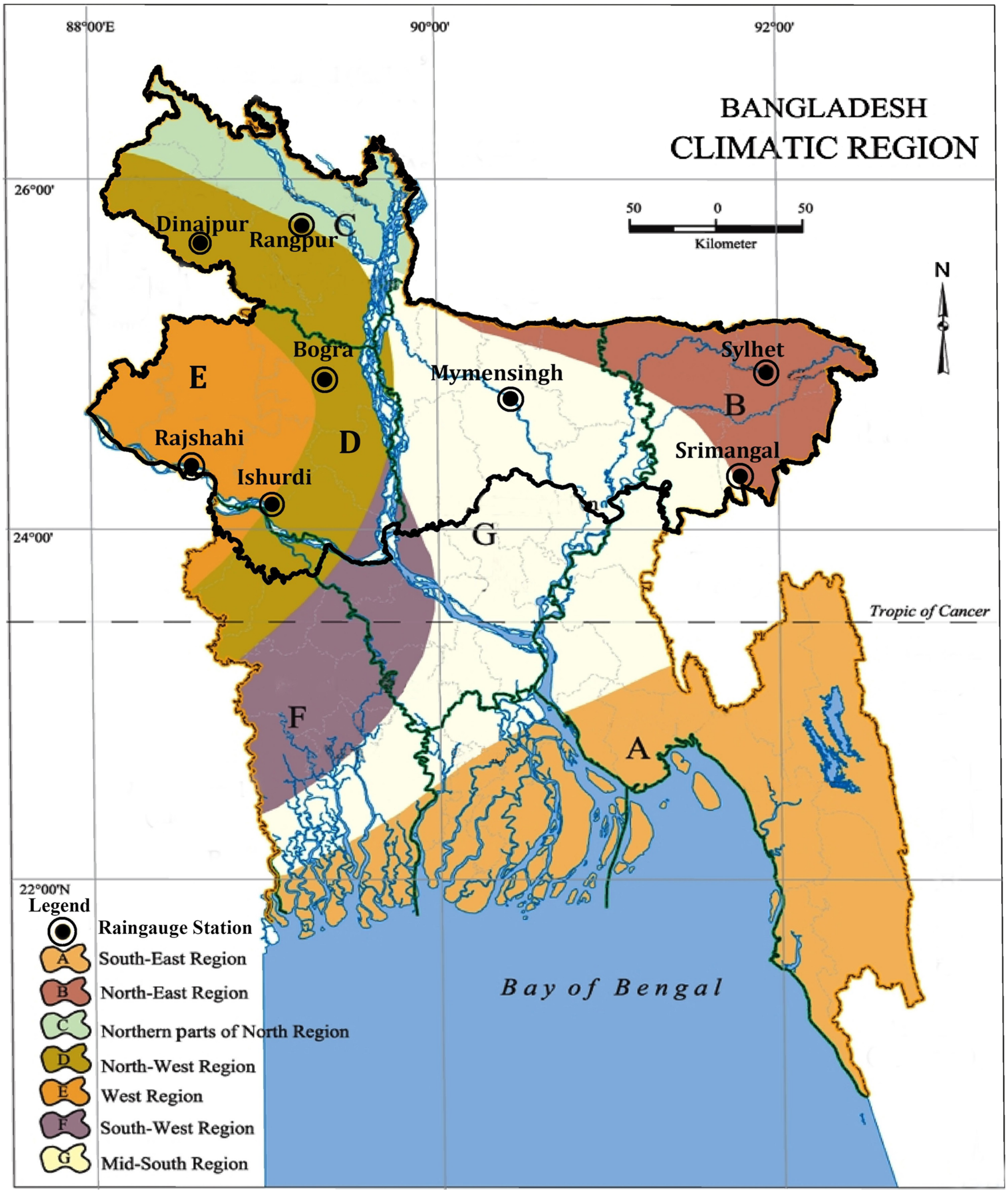

Fig. 1 Location of study area in Bangladesh (modified after Rashid 1991). The *thick black line* in upper segment represents boundary of the study area

Table 1 Seasonality index classes (after Walsh and Lawler 1981)

SI_i	Precipitation regime
<0.19	Precipitation spread throughout the year
0.20–0.39	Precipitation spread throughout the year, but with a definite wetter season
0.40–0.59	Rather seasonal with a short drier season
0.60–0.79	Seasonal
0.80–0.99	Markedly seasonal with a long dry season
1.00–1.19	Most precipitation in <3 months
>1.20	Extreme seasonality, with almost all precipitation in 1–2 months

The possible trend in individual seasonality index was calculated using the Mann-Kendall trend test (Sonali and Kumar 2013). Besides, the sequential Mann-Kendall test (Lu et al. 2004; Shifteh Some'e et al. 2012) was applied to identify if there were any shift in seasonality index or if there were any trend fluctuations. Kendall's tau (Hollander et al. 2014) was used to identify strength of the trend.

5 Results

5.1 Variability of rainfall

It was observed that variability of the winter rainfall decreases from northwestern (highest 117.10 % at Bogra) to the north-eastern (lowest 81.42 % in Srimangal) part of northern Bangladesh. Winter variability was found greater than 100 %, except at Rangpur (89.07 %), Sylhet (86.80 %), and Srimangal (81.42 %). This higher variability indicates an exceptionally non-linear winter rainfall characteristic. However, the existence of several zero values (a winter without rainfall) could have certain impacts for being variability greater than 100 %. Post-monsoon stands in the second highest. The maximum post-monsoon rainfall variability was found at Dinajpur (94.60 %), whereas lowest at Srimangal (59.49 %). Concluding annotations can be that post-monsoon rainfall becomes consistent towards the northeastern region from the northwestern region of northern Bangladesh. Pre-monsoon rainfall has less variability than winter and post-monsoon rainfall but has higher variability than monsoon rainfall. The highest pre-monsoon rainfall variability was found in Ishurdi, whereas lowest in Sylhet. Monsoon rainfall has a substantial impact on the economy of the region especially in the low-lying northeast climatic zone of Bangladesh. The significant influence of monsoon rainfall on agro-economy, fish culture, and water resources gives this season higher priority in analysis. We found lower variability of monsoon rainfall compared to that of the other three seasons. While monsoon rainfall variability was found higher for western part (highest 28.28 % at Ishurdi), lowest variability was detected in the eastern segment of northern Bangladesh. There were 38 % difference between the highest and the lowest monsoon rainfall variability for this region.

The annual rainfall variability is low as compared to inter-seasonal variability and found very close to that of the monsoon season. It may be because monsoon rainfall contributes about 80 % of annual rainfall. The maximum annual rainfall variability was found in Ishurdi (26.25 %), whereas minimum in Sylhet (15.52 %).

Figure 2 shows the circulation of rainfall variability in northern Bangladesh. The figure indicates that rainfall

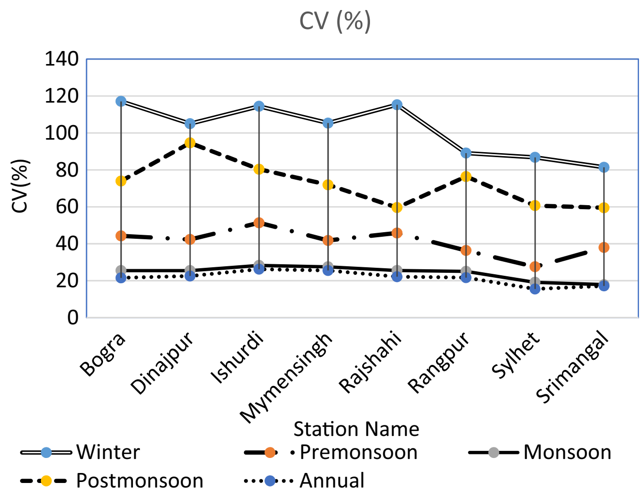

Fig. 2 Station-wise variability of annual and seasonal rainfall in northern Bangladesh. *Horizontal axis* indicates the station names and *vertical axis* represents the values of coefficient of variation in percentage

variability is lower at the lower altitude areas (Sylhet and Srimangal).

5.2 Seasonality of rainfall

Seasonality index (SI) was calculated using mean monthly rainfall at first. The SI values range from 0.728753 to 0.902487 meaning "seasonal" to "markedly seasonal with a long dry season" rainfall characteristics in this area. It was seen that stations with lower variability have more likely seasonal rainfall behavior. Results of the seasonality index values are given in Table 2.

Walsh and Lawler (Walsh and Lawler 1981) suggested that using mean monthly rainfall underestimates the resulting index, because averaging smoothes year-to-year noise in the monthly precipitation values (Sumner et al. 2001). Therefore, further study was conducted using yearly individual seasonality index.

Initially, the yearly individual seasonality index was calculated for all of the stations of northern Bangladesh. A long-term mean individual seasonality index was then

Table 2 Seasonality index for northern Bangladesh

Station	$\overline{SI}$
Bogra	0.853486
Dinajpur	0.902487
Ishurdi	0.821328
Mymensingh	0.812971
Rajshahi	0.843713
Rangpur	0.868322
Srimangal	0.728753
Sylhet	0.793508

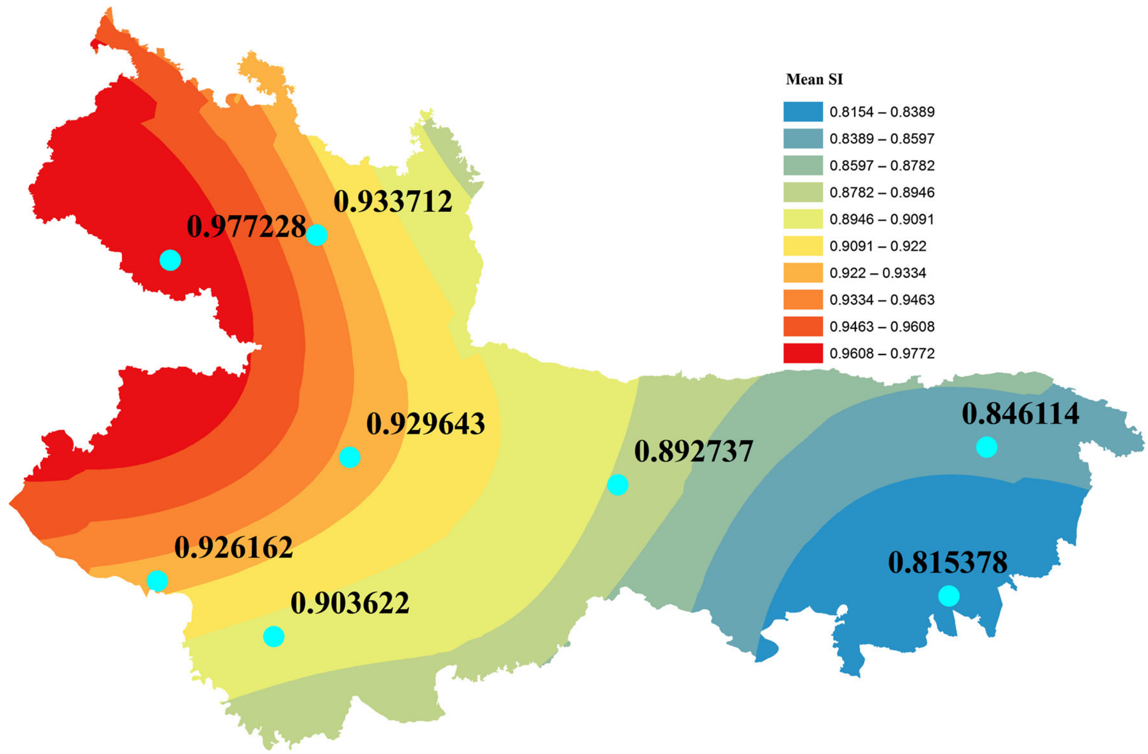

Fig. 3 Spatial distribution of $\overline{SI}_i$ values for northern Bangladesh

calculated for each station using yearly individuals. $\overline{SI}_i$ values range from the lowest 0.815378 at Srimangal to the highest 0.977228 at Dinajpur. Therefore, according to Walsh and Lawler (1981), northern Bangladesh falls in the classification "markedly seasonal with a long dry season". $\overline{SI}_i$ values were found lower at the low-lying northeastern part of the study area, indicating shorter dry period than the western part (Fig. 3).

Once the rainfall seasonality was derived, the Mann-Kendall trend test was applied to check whether yearly seasonality index has a decreasing or increasing trend. The Mann-Kendall test showed decreasing trend in yearly seasonality index for Dinajpur, Ishurdi, Rajshahi, Rangpur, and Srimangal. However, they were found statistically non-significant in 95 % confidence interval. The results of Mann-Kendall test are shown in Table 3. Kendall's tau statistics also shows a week strength of trend over time. The sequential Mann-Kendall test was applied to identify trend fluctuation. The sequential Mann-Kendall test recognizes non-significant identical decreasing trend for Ishurdi and Rangpur. On the other hand, the sequential fluctuation was observed for Dinajpur and Mymensingh. A decreasing trend was observed for Srimangal after the 1980s. However, they were non-significant at 95 % confidence limit. No commendable change was detected for the other stations. The results of the sequential Mann-Kendall test are shown in Fig. 4. Overall concluding remarks from the Mann-Kendall test and the sequential Mann-Kendall can be that there is no distinguishable change in rainfall seasonality in this area.

The relationship between $\overline{SI}_i$ and SI has been examined (Fig. 5). This type of relation can be useful in future $\overline{SI}_i$ calculation. A significant linear correlation ($r^2 = 0.9656$) was found, which is expressed by the following formula:
$\overline{SI}_i = 0.9607SI + 0.1076.$

This relationship is site specific; therefore, it cannot be generalized. While a linear form shows a significant correlation in the present analysis, often exponential form can perform better based on data. So it is advised to check other practices of regression also.

Albeit the spatial distribution of mean seasonality index is presented in Fig. 3, depicting a relation between longitude and

Table 3 Mann-Kendall test results for yearly individual seasonality index

Station name	Kendall S	Sen slope
Bogra	9.0000	6.6495E-5
Dinajpur	−1.0000	0
Ishwardi	−199.0000	−0.002
Mymensingh	11.0000	5.5955E-5
Rajshahi	−101.0000	−0.0007
Rangpur	−214.0000	−0.0016
Srimangal	−51.0000	−0.0005
Sylhet	27.0000	0.0002

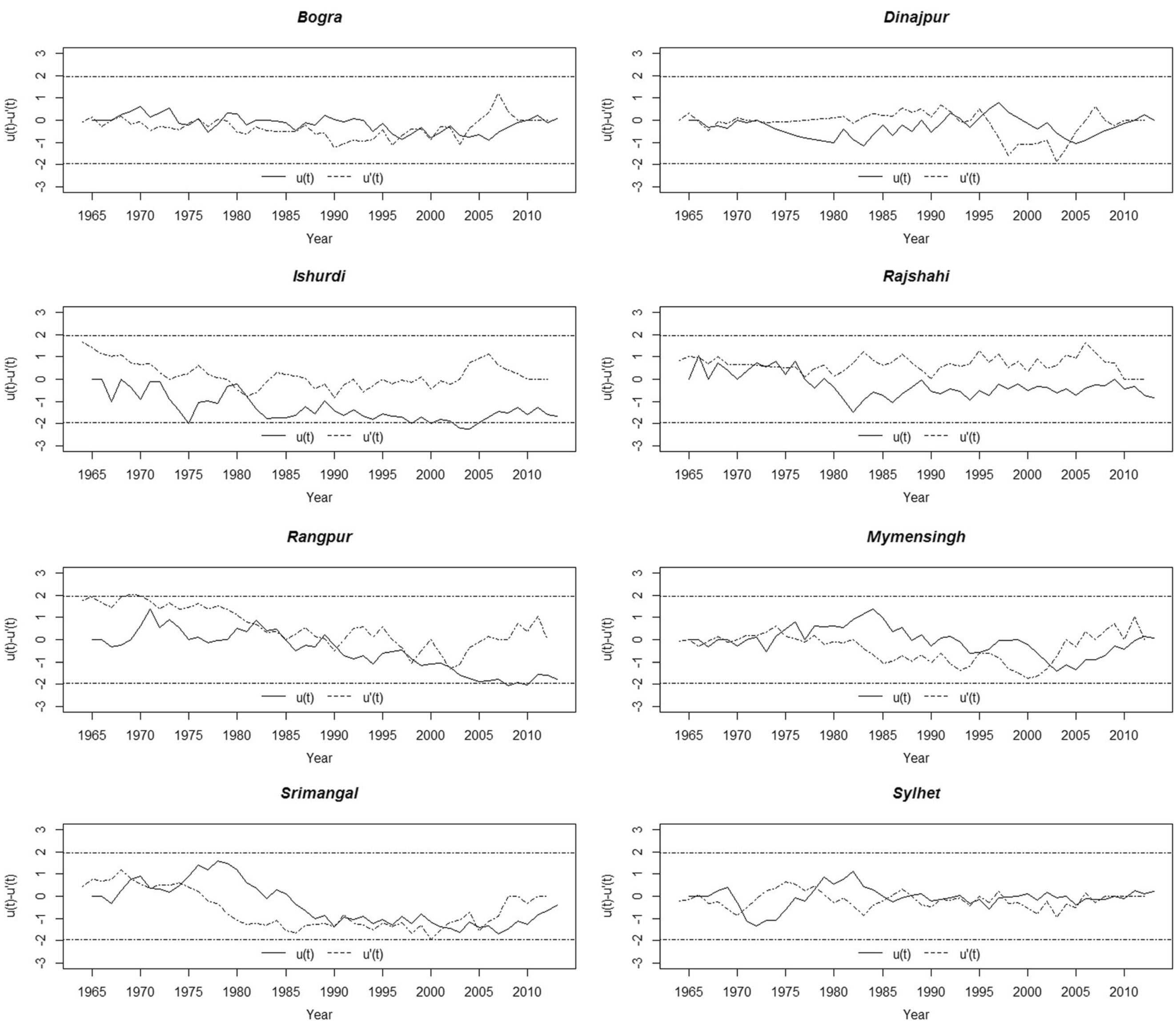

Fig. 4 Sequential Mann-Kendall test statistics for individual seasonality index. *Horizontal dashed line* indicates upper limit and lower limit of 95 % confidence limit

mean individual seasonality index for northern Bangladesh might be worthy. This reveals a considerable linear relationship between them (Fig. 6). The equation derived from the relationship may further be used to identify mean seasonality index for any location in the study area.

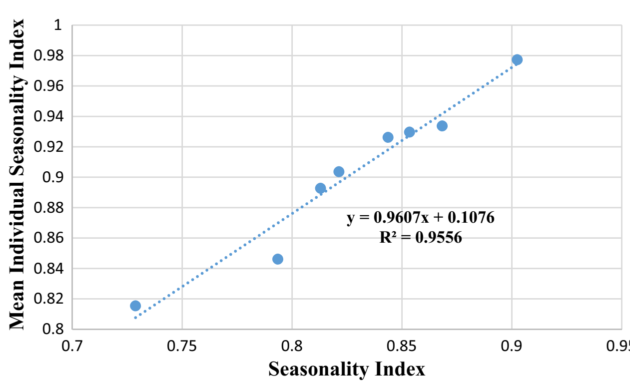

Fig. 5 Scatter plot diagram of seasonality index ($\overline{SI}$) vs mean individual seasonality index ($\overline{SI}_i$). The *dotted line* represents liner regression line

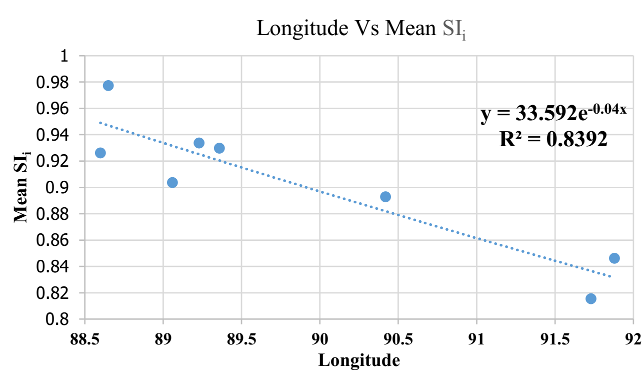

Fig. 6 Relationship between longitude and mean individual seasonality index

6 Conclusion

This study revealed that winter rainfall has the maximum rainfall variability (greater than 100 % in some cases) while monsoon has the minimum (<30 %). The seasonality index discovered that rainfall in Bangladesh is characterized by markedly seasonal with a long dry season. Lower seasonality index indicates shorter dry periods for Sylhet, Srimangal, and Mymensingh stations. Minimum variability and the seasonal behavior of rainfall at the northeastern Bangladesh are perhaps due to its location in the vicinity of the world's wettest place Cherrapunji (India). Cherrapunji receives the largest amount of rainfall in the world, and distribution of rainfall is more consistent there.

Time series analysis of individual seasonality index shows no significant change in seasonality. However, increasing trend in rainfall seasonality for some of the locations (i.e., Sylhet, Bogra, and Mymensingh) impends longer dry periods meaning potential drought phenomenon in the near future.

In contrary, a decreasing trend in seasonality index could be either a threat or a blessing in agricultural production. Still, impacts of seasonality change cannot be specified until cultivation pattern and response of crop varieties to seasonal changes are thoroughly studied. Besides, on set of different seasons have substantial effect on several crop varieties. Therefore, arrival and withdrawal date of various seasons also require a detailed study.

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